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Fatigue resistance of reinforcing steel bars

Peter Kopas[a,*], Lenka Jakubovičová[a], Milan Vaško[a], Marián Handrik[a]

[a]*University of Žilina, Faculty of Mechanical Engineering, Department of Applied Mechanics, Univerzitná 1, 010 26 Žilina, Slovakia*

Abstract

During the last few years there has been an intensification of interest in the fatigue performance of steel reinforcement bars in concrete structures. Although fatigue has not proved to be a problem to date, loading cycles are becoming increasingly severe so that the margin of reserve strength is progressively being reduced. In this paper the authors present and discuss results of fatigue life tests performed for reinforcing steel bars which is one of the most widely used construction material in the world. Endurances can be influenced by type of steel, geometry and size of the bars, nature of the loading cycle, welding and presence of corrosion. The experimental part deals with fatigue testing of specimens for identification of the strain-life behaviour of reinforcing bars and determining the number of cycles to failure.

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Keywords: low-cycle fatigue; reinforced concrete; model; reinforcing steel

1. Introduction

Fatigue was initially recognized as a problem in the early 1800`s when investigators in Europe observed that bridge and railroad components were cracking when subjected to repeated loading [1]. As the century progressed and the use of metals expanded with the increasing use of machines, more and more failures of components subjected to repeated loads were recorded. Today, structural fatigue has assumed an even greater importance as a result of the ever increasing use of highstrength materials and the desire for higher performance from these materials. Steel reinforcing bars have numerous applications. They are most frequently used in reinforced concrete structures as reinforcements transferring tensile stresses. For that reason reinforcing bars can be found in slab, beam and pillar

* Corresponding author. Tel.: +421 41 513 2984; fax: +421 41 565 2940.
E-mail address: peter.kopas@fstroj.uniza.sk

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reinforcements in buildings and industrial structures such as tanks, foundations, chimneys, cooling towers, bridges etc. Presently, reinforcing bars are made of numerous steel grades characterised by high strength values.

Designs of highway bridges are assessed for lives of 120 years during which time up to 7.10^7 cycles of traffic induced stress may be applied [2]. To date there have been no fatigue fractures reported for concrete highway bridges in normal service. It is possible, however, for reinforcement bars to fail without any outward signs of structural distress except local cracking of the concrete. There have also been a number of reported cases of fatigue cracking in welded joints of steel girders supporting concrete bridge decks [3]. Stress ranges in bridge deck reinforcement due to live loads are difficult to calculate with precision because of the questionable assumptions that must be made for effects such as load spreading beneath vehicle wheels and cracking of the concrete. Normal design calculations indicate that stresses should be low; current practice is to prevent unacceptable strains occurring in the reinforcement and at the serviceability limit state the elastic stresses should not exceed 80% of the characteristic strength defined as the 0.2% proof stress. Stress ranges can be higher if there is a compressive element in the dynamic load-cycle. In practice measured stresses are usually lower than design values.

There has been much research into fatigue of reinforcement. This has been intensified in recent years by the introduction of higher strength materials, the development of advanced applications such as offshore structures and the adoption of new design codes. In addition it is becoming recognised that features such as corrosion, type of bar, form of manufacture, etc. can cause the fatigue lives to be substantially lower than are normally given in reference data. Although attention has been focussed mainly on the reinforcement bars, consideration must also be given to the fatigue performance of concrete in relation to bridges and highway pavements. Fatigue tests of reinforcing bars at static loads are not accompanied by any problems, yet tests of reinforcing bars at changing loads pose certain difficulties related to the fact that fatigue cracks are usually generated in the area where test specimens are fixed in the jaws of a testing machine, i.e. where significant notches are present. Then, the results of such tests cannot be regarded as reliable and should be rejected. While testing reinforcing bars it is not possible to make classic contracted specimens, e.g. those used during tests of other base metals as such specimens must be tested in the as-delivered state, i.e. without any interventions in their cross-sections [4, 5].

2. Types of reinforcing bar fatigue test

Axial tests are usually conducted on “as received” bars in conventional fatigue machines. The advantages are: (a) tests are cheap and can be run at relatively high frequencies, up to about 150 Hz, so that long endurances can be obtained quickly; and (b) applied stresses can be calculated unambiguously. The great disadvantage is that it is difficult to grip the bars without introducing high local stresses which cause premature failures. It is also difficult to avoid the introduction of secondary stresses caused by lack of straightness in the bars or poor alignment in the testing machine. A variety of methods have been used in attempts to grip the bars satisfactorily, all of which have involved introducing an interlay between the bar and grips so that load transfer is spread evenly over the bars' surface. A standard procedure for axial testing has been usually recommended. The minimum free length between grips must be equal to the greatest of: 30 times the nominal diameter, eight times the pitch of helical ribs (if present) or 500 mm. It is argued that shorter free lengths can increase experimental scatter. The recommended loading frequency is between 3 and 10 Hz. However, this range of frequencies is unduly restrictive because satisfactory testing can be conducted at up to 150 Hz. In order to simulate the effect of concrete on a bar it was also necessary to make specimens covered by a concrete coating in the middle of their measurement part [6].

Bending fatigue tests are usually made on concrete beams having a single reinforcement bar. The main advantage is that the test beam simulates service conditions such as the interactive effects at the steel-to-concrete interface. However, cyclic frequencies are limited by the high ranges of deflection and the necessity to avoid local heating due to friction at cracks in the concrete. Tests are commonly conducted at about 3 Hz so that endurances of 10^7 cycles take as long as six weeks. Another disadvantage is that for calculation of the stresses it is necessary to make assumptions about the load carrying contribution of the concrete and the accuracy of placement of the reinforcement. A variety of designs have been used including three-point bending to simulate conditions at the centre of short spans, fourpoint bending to simulate long spans and bent beams as used in the DIN specification. Tests by Pfister and Hognestad [7] to assess the bent beam have shown that it gives consistently lower fatigue strengths than four-point bending of a straight beam. Most bending tests have been loaded by hydraulic jacks with spreader beams for fourpoint bending. The load cycles are usually sinusoidal and controlled to give a constant amplitude of load. Hydraulic equipment, however, is expensive both for capital cost and running costs. In consequence few tests have been run for durations exceeding 10^7 cycles because of the long times of machine occupancy demanded at frequencies no higher than 3 Hz. In order to overcome this problem a simple mechanical test rig employing a small electric motor and cranks has been designed [8].

3. Experimental material and strain-life data results

Twenty smooth specimens were tested under strain controlled conditions in order to identify the strain-life behaviour of the experimental material. After machining, the specimen surfaces were mechanically polished. The experiments were carried out in an electro mechanic fatigue test machine, developed on University of Žilina. Design of experimental equipment has been based on mechanical principle. The constant rotation is generated by excenter and linkage mechanism. By changing of excentric magnitude it is possible to change a loading magnitude. Also if we change a length of connecting crank on the experimental equipment, there will be change in a loading cycle character. Power of device is secured by two synchronic electromotors with frequency converters from 0.5 Hz to 100 Hz. Loading frequencies are identical with frequency of rotation drive. Synchronization of the electromotors is secured using by electronics and allows synchronization of loading amplitudes. Synchronization of electromotors also allows setting phase shift for individual loading levels.

For evaluation of fatigue curves it needs to know stress and strain conditions on individual loading levels. A sinusoidal waveform was used as command signal. The fatigue tests were conducted with constant strain amplitudes, at room temperature, in air. The specimens were cyclic loaded under strain control with symmetrical proportional bending loading, with a nominal strain ratio, R_ε = -1. The computational fatigue tests were performed under cyclic loading with the zero mean value. Frequency of each analysis was equal to 30 Hz.

This research was conducted on an W.Nr. 1.0429 reinforcing steel. It is a versatile constructional material which is widely used in the construction industry for making of the reinforced concrete. Passive steel reinforcing bars, also known as rebars, should necessarily be strong in tension and, at the same time, be ductile enough to be shaped or bent. Steel rebar is most commonly used as a tensioning devise to reinforce concrete to help hold the concrete in a compressed state. The typical mechanical and chemical composition of the W.Nr. 1.0429 reinforcing steel is shown in Table 1 and Table 2. The material used in this research was delivered in the form of a cylindrical shape with a diameter 10 mm. The length of cylindrical bars was 150 mm. The material was in a rolled state.

Table 1. Chemical composition of the W.Nr. 1.0429 reinforcing steel (weight %).

C	Si	Mn	Ni	P	S	Cr	Mo	V	N	Nb	Al	Cu	-
max 0.16	max 0.45	max 1.3	max 0.3	max 0.025	max 0.2	max 0.3	max 0.1	max 0.04	max 0.012	max 0.04	0.015–0.06	max 0.25	CEV< 0.4

Table 2. Mechanical properties of the W.Nr. 1.0429 reinforcing steel.

Ultimate tensile strength	520 – 770 MPa
Tensile yield strength	410 MPa
Elongation at fracture	14 %

From experimentally measured values of number of cycles to failure was created uniaxial fatigue curve, which is shown in Fig. 1. For fatigue test interpretation on each loading levels it is necessary to know the plastic strain amplitude (Manson-Coffin curve) or stress amplitude (Wöhler curve) applied on each cycle loading level.

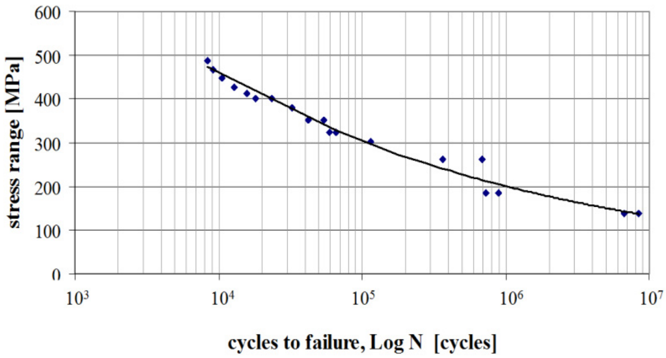

Fig. 1. S-N curves for W.Nr. 1.0429 reinforcing steel.

For that it is necessary to analyze the stress and strain maximum values by FEM [9–12]. The specimen model was created by the finite-element program ADINA. The material was assumed plastic-bilinear; the true stresses were obtained from a real stress-strain graph. The tetrahedron linear element type was automatically generated. The "Load Plot" function was defined by excenter setting with excentricity 1 mm. At the fix point shell and beam elements were used for hammer simulating. From the computational analysis can be seen that the area with the greatest concentration of stresses or the place with the higher deformation was localized in the middle of the rod radius, Fig. 2.

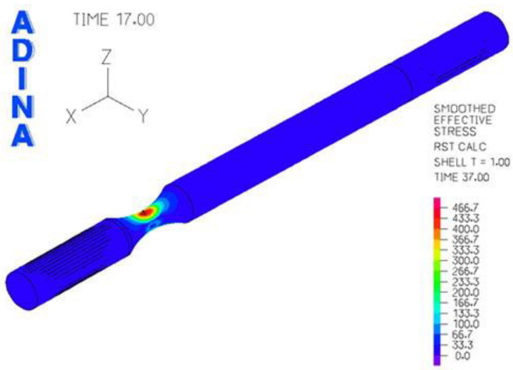

Fig. 2. Result of FEM analysis.

4. Conclusion

In this study, the low-cycle fatigue behavior of W.Nr. 1.0429 reinforcing steel smooth bars was experimentally evaluated. Tests were performed under strain controlled conditions bending loading on machined bar specimens by means of a simple loading apparatus that allowed to reach high strain levels. Each type of fatigue testing has merit and the selection of the one or the other is a question of convenience in relation to what aspect of fatigue is being studied rather than any more fundamental issue. In our case it has been assumed that executed fatigue bending tests on reinforced steel bars more closely reproduce service conditions and give a realistic assessment of performance for features that are influenced by the concrete. Generally we can say that the results are in good agreement with the results published by other authors [1–4]. On the basis of the tests performed, the following conclusions were formulated: The fatigue resistance of reinforcing steel increases with decreasing stress amplitude continuously in the cycles of number region. It is possible to perform fatigue tests of reinforcing bars if the appropriate specimen preparation methodology is applied.

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References

[1] O. Bokůvka, G. Nicoletto, L. Kunz, P. Palček, M. Chalupová, Low & high frequency fatigue testing, CETRA and Univerzity of Žilina, 2002.
[2] Steel Concrete and Composite Bridges, BS 5400, British Standards Institution, London, 1978.
[3] G.P. Tilly, Fatigue problems in highway bridges, Bridge Engineering, Transportation Research Record 664 (1978) 93–101.
[4] P.J.E. Forsyth, The Physical Basis of Metal Fatigue, Blackie and Son, London, 1969.
[5] V. Dekys, A. Sapietova, O. Stevka, Understanding of the dynamical properties of machines based on the interpretation of spectral measurements and FRF, Applied Mechanics and Materials 486 (2014) 106–112.
[6] P.J. Yanopoulos, A.D. Edwards, Fatigue characteristics of hot-rolled deformed bars. Civil Engineering Department Report CSTR 76/1, Imperial College, London, 1976.
[7] J.F. Pfister, E. Hognestad, High strength bars as concrete reinforcement, J. Portland Cement Assoc. Res. Devl. Lab. 6 (1964) 65–84.
[8] M. Žmindák, V. Dekýš, P. Novák, Fracture Mechanics Approach of delamination composite plates, Advanced Material Research 969 (2014) 176–181.
[9] M. Žmindák, D. Riecky, Meshless Modelling of Laminate Mindlin Plates under Dynamic Loads, Communications 14 (2012) 24–31.
[10] A. Sapietová, M. Sága, P. Novák, Multi-software platform for solving of multibody systems synthesis, Communications 14(3) (2012) 43– 48.
[11] A. Sapietová, M. Sága, A. Shimanovsky, M. Sapieta, Mobility of multibody systems in terms of their incorrectness, Comunications 16(3A) (2014) 6–12.
[12] P. Kováčiková, J. Vavro, J. Vavro Jr., Experimental and numerical analysis of fatigue during the cyclic loading, American Journal of mechanical engineering 2(7) (2014) 295–298.